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THE ROYAL ASTRONOMICAL SOCIETY OF CANADA

DEVOTED TO THE ADVANCEMENT OF ASTRONOMY AND ALLIED SCIENCES

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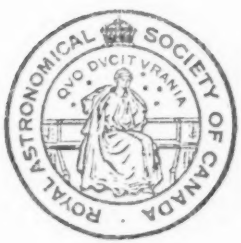

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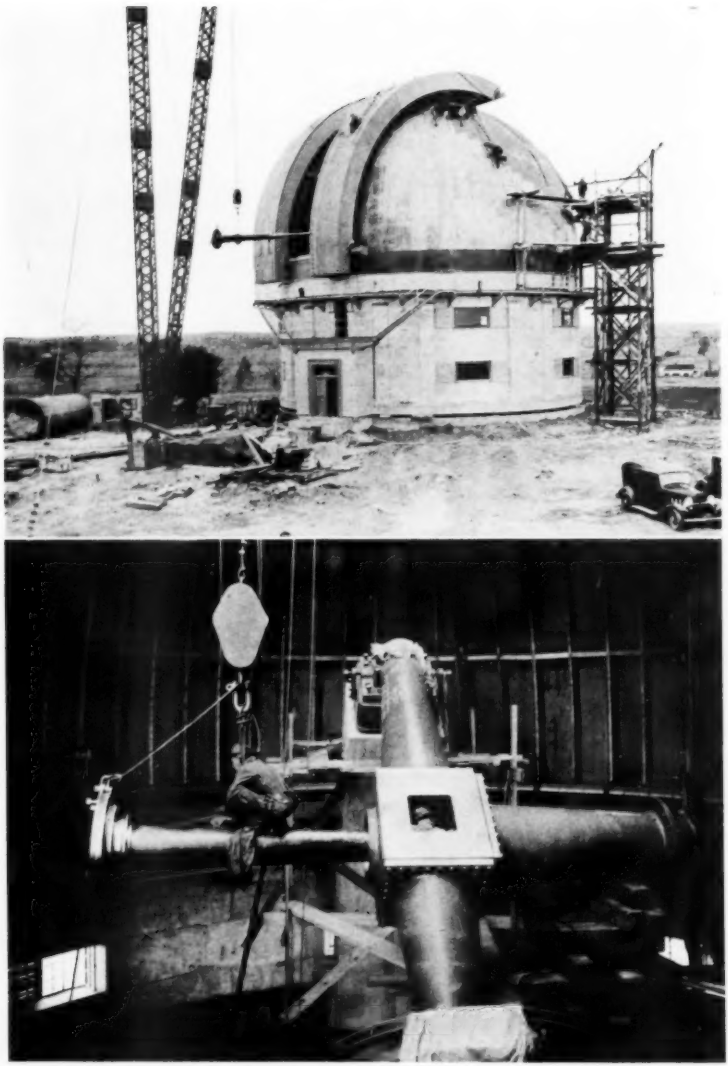
ERECTING THE 74-INCH TELESCOPE OF THE DAVID DUNLAP OBSERVATORY

Left—Hoisting the polar axis. *Right*—Guiding the lower end into place

PLATE X



ERECTING THE 74-INCH TELESCOPE

Above—Hoisting the declination axis. *Below*—Guiding this axis through the polar axis.

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Vol. XXVII, No. 10 DECEMBER, 1933 Whole No. 229

THE 74-INCH TELESCOPE OF THE DAVID DUNLAP OBSERVATORY

By C. A. CHANT

(WITH PLATES IX AND X)

THE photographs reproduced in Plates IX and X illustrate progress in the installation of the 74-inch telescope of the David Dunlap Observatory.

The circular building with its revolving dome arrived at the end of July. It was supplied by the firm which constructed the telescope, namely, Sir Howard Grubb, Parsons & Co. of Newcastle-on-Tyne. The structural part was produced by the Cleveland Bridge Co., of Darlington, but the intricate gear for revolving the dome, moving the shutters and wind-screens, &c., was made in Newcastle. As shipped it weighed 210 short tons. It was loaded on the steamship *Havtor* in England and brought directly to the Toronto harbour. From the dock it was taken by truck to the site fifteen miles away. The building had been erected in England and was speedily re-erected by the Dominion Bridge Co. of Toronto.

The diameter of the building is 61 feet and the walls are two feet thick. They are sheeted inside and outside with heavy galvanized iron. To bind the sheets together some 32,000 bolts were used. The revolving dome is sheathed with "agasote" a preparation of papier maché and a good heat-insulator. The outer covering is one-half inch thick and the inner one three-eighths of an inch. Over all is a covering of copper for protection from the weather. The covering of the dome was done by Sullivan and Fried, who erected the Administration Building with the domes on it.

The telescope—all but the large mirror—was shipped from Newcastle by the steamer *Cairnross*. At Montreal it was transferred to freight cars which brought it to Toronto. Then it was carted to the site and erected by the Dominion Bridge Co. As one piece of the telescope, the polar axis assembly, weighed 16½ tons a special 20-ton crane with a boom 92 feet long was erected to handle it. First, the housings of the bearings were carefully put in place on the north and south piers, and the axis was prepared. The driving and other wheels were placed on the south end; then when the large crane had raised the axis from the ground a second crane lifted one end until the axis was inclined to the horizontal at an angle of about 44° (the latitude of the site). The lower end was tied to the hook of the large crane so that the inclination of the axis should be maintained. Then the large crane raised the axis high in the air, passed it through the 15-foot slit of the dome and gently lowered it to the pier. The whole operation from leaving the ground until in its final position occupied less than an hour.

The left picture in Plate IX shows the axis in mid-air and the right picture shows the workmen guiding the lower bearing into its place. Then the declination sleeve weighing 3 tons was raised into position and bolted to the cubical portion of the polar axis. This was done on the morning of October 23.

In the afternoon the declination axis, weighing 3½ tons, was raised and put in place. In the upper picture of Plate X the axis is seen passing into the dome, while the lower picture shows it being guided through the polar axis and the declination sleeve.

At the present date (November 27) the large switchboard with its relays for controlling the fifteen motors and their circuits is being erected on the ground floor. The ground and observing floors, which will be of cement, will soon be put in place.

The great disc of Pyrex glass, which was poured at the Corning Glass Works on June 21, after three months in the annealing oven was removed from its mould. By means of polarized light it was examined for internal strains and it was found to be exceptionally good. On October 5 it was shipped from Corning, N.Y., to Montreal and left that port on October 15 on the same ship which brought over the telescope. The disc is now at the optical works in Newcastle where it is being ground into shape.

THE MARKINGS AND ROTATION OF MERCURY

By E. M. Antoniadi

IT is a well-known fact that this planet has been singularly neglected by astronomers, so that the greatest confusion is reigning as to the reality and configuration of its spots, the duration of its rotation period, or even the existence of its atmosphere. This uncertainty strikes its roots in the smallness of the disc of Mercury; in the practical hopelessness of detecting well-defined markings on his surface at the very low altitude, and consequent rippling air, of twilight and dawn; and in the difficulty of finding the planet itself without an equatorial mounting, at daytime, high above the horizon, and in the overpowering glare of the Sun.

In the beginning of the XIXth century, Schröter drew mountains, a dark streak, and other spots on Mercury, from which Bessel deduced a rotation period of $24^h\ 0^m\ 53^s$ round an axis inclined some 70° to the plane of the orbit. But these objects were illusive. Yet Schröter had called attention to two features which were subsequently confirmed: (1) that the phase was always smaller than it ought to be theoretically; and (2) that the S. cusp looked very often blunted. This last phenomenon was well explained by Schiaparelli, as due to the presence of some dusky area near the S. pole, although he did not draw any such marking on his map of the planet.

At about the same time as Schröter, Herschel could detect no spots on Mercury. Prince, in 1867, Birmingham, in 1870, called attention to their observation of white areas, while Vogel seemed to recognize other markings. In 1879, Flammarion saw no spots; and, from 1876 to 1881, Trouvelot could only catch a glimpse of a white area at the N. cusp of the crescent phase.

In 1882, De Ball drew a curved dusky shading on the morning phase, which Schiaparelli later identified with one of the markings seen by himself; and, in the same year, the eminent English observer, Denning, saw several spots, which I was enabled to confirm in 1927, and from which he concluded that the rotation period was about 25^h.

Between 1881 and 1889, Mercury was scrutinized in broad daylight by Schiaparelli with his customary perseverance and with the startling result that the period of rotation was found to be

equal to the period of revolution, the planet completing a rotation in $87^{d}.969256$ round an axis almost perpendicular to the orbital plane.

It is generally stated that Lowell *did* confirm the conclusions of Schiaparelli. Yet, in his 1896-1897 map, he does not show a single marking observed at Milan, or elsewhere, but only an enormous number of illusive blackish, linear, canals, some perpendicular, others parallel, others inclined to the plane of the orbit of the planet.

On August 31, 1900, Barnard, using the 40-inch at Yerkes, detected, in broad daylight, "three or four large darkish spots, very much resembling those seen on the Moon with the naked eye", adding that "one of these dark markings south preceding the centre of Mercury was specially noticeable."

In 1907 and the years following, Jarry Desloges and Fournier drew some dusky spots of Schiaparelli's chart, which Sormano believed to have been probably confirmatory of the long rotation period.

Five years later, Danjon, using a 7½-inch refractor in Paris, depicted admirably some real dark markings on the evening phase, confirming Schiaparelli, and thus succeeding with a modest instrument located in the smoke and dust of the great city there where Lowell had failed with a powerful telescope in the elevated and so highly-vaunted table-lands of Arizona.

The conclusions of Schiaparelli met a cool reception. Yet a handful of astronomers, among whom C. A. Young, E. W. Maunder, and A. C. D. Crommelin, entertained but little doubt as to the accuracy of the results of the Italian, while the majority of scientists opposed to them a sturdy scepticism. It was thus only four years ago when Graff wrote that almost nobody now believed in the 88-day rotation period of Schiaparelli, controverted, as he thought, by the radio-metric measures executed on the small disc of the planet. I never accepted the deductions drawn from the interesting indications of the thermo-couple on the planets; and, in the case of Mercury at least, my distrust was proved to be founded by the unexceptionable evidence of observation.

Prudence naturally prompted me to have no opinion on the rotation period of that planet since I had not studied it telescopically; but, convinced that the powerful refractor of 33 inches

aperture at Meudon could easily help to solve the mystery, I asked my director, M. Deslandres, the permission to use that instrument occasionally on Mercury at daytime—a demand which was favourably received by that most distinguished astronomer, and for which I wish to express here my feelings of deep gratitude.

The planet was thus followed near the meridian during the summer months of 1927, 1928 and 1929; and it was soon obvious that its markings, which were often seen quite distinctly, appeared fixed with regard to the terminator for hours together on the same day. Yet they showed, day after day, a pronounced movement of libration in longitude, such as would be necessitated by a uniform rotation of Mercury in a period equal to that of the revolution round the Sun. The axis was found almost perpendicular to the plane of the orbit, its inclination not reaching 7°. Here, then, we had a complete vindication of the conclusions of Schiaparelli.[1]

My results are embodied in the figure accompanying this paper. A closer scrutiny with the large telescope, and with better definition under a high Sun, would have revealed a much more detailed structure; but the present map gives a satisfactory view of the most important markings seen by me with certainty on that desolate world.

The colour of Mercury looked at daytime in the 33-inch almost comparable with that of the moon in twilight. The planet appeared yellowish with a slight roseate tinge on the azure of the sky; while a distinct neutral-grey hue was characteristic of its dusky areas.[2]

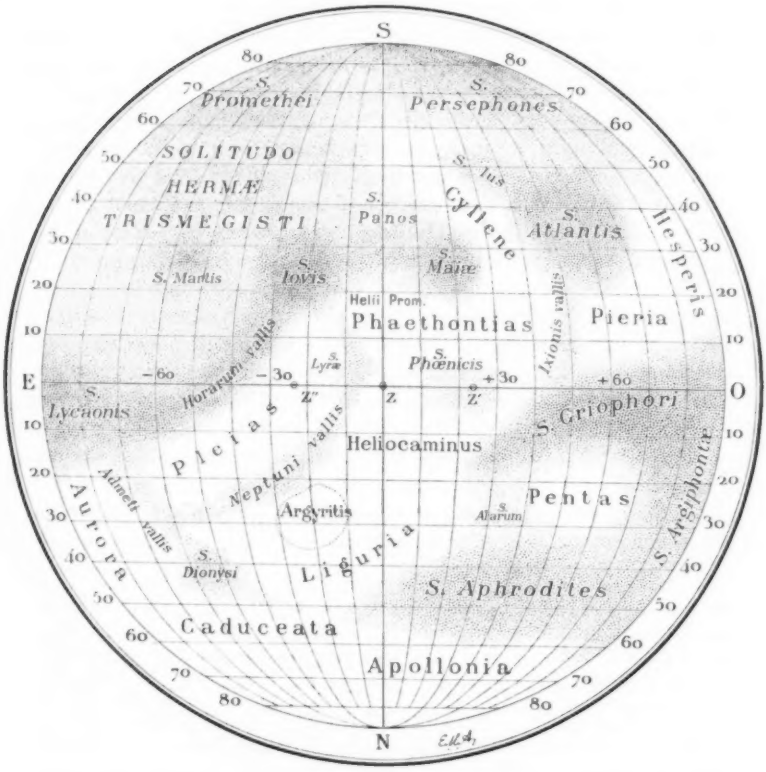
[1] I must state that a very close scrutiny of Venus near the meridian for many months in 1928 with the large telescope has convinced me that we know nothing about her rotation period. Schiaparelli's period of 225^d rests on no decisive spots, but on an effect of contrast. The faint markings seen by me on Venus were manifestly atmospheric and variable from one day to the other. A calculation of the solar tides on Venus has shown me that her rotation was slackened only a little more than that of the Earth. Should the absence of a satellite constitute an indication of a slow original rotation (which is doubtful), then the neighbour planet may have a rotation period extending over weeks; otherwise the period would be only somewhat longer than the 24^h of the Earth.

[2] Schiaparelli found that these spots had a pale brown tinge. This I could not confirm, in spite of the great superiority of the large instrument in showing colour. Mars, Jupiter, and Saturn display wonderful hues in it; but the dark spots of Mercury always appeared to me quite as colourless as the Maria of the Moon.

Chart of Mercury

Embodying all the markings observed on the Planet with the 33-inch Refractor at Meudon, in 1927, 1928, and 1929

By E. M. Antoniadi



The central point, Z, is supposed to have the Sun at the zenith when the planet is in perihelion or aphelion; but as the projection is not an orthographic one, the Chart does not give the approximate appearance of Mercury in superior conjunction with the Sun.

The letter S. stands for the initial of the Latin word *Solitudo*, wilderness; and the abbreviation *Prom.* stands for *promontorium*.

Argyritis is a bright white region, and was discovered in 1882 by the English astronomer, W. F. Denning.

With the view of avoiding the use of periphrases in the description of the spots, I have given names to the latter, generally drawn from the Greco-Egyptian mythology of the god Mercury. A few names were inspired by the desert state and tremendous heat prevailing on the planet; and I deemed it a duty to christen a bright area by the name of the antique *Liguria*, in pious remembrance of Schiaparelli, born at Savigliano, for his truly wonderful discovery of the chief spots and slow rotation of Mercury with a small telescope.

The dusky markings of the planet appear larger in the 33-inch than in the telescopes of the Italian astronomer—a fact due to diminished diffraction in the big glass, and one, too, which yields a precious independent proof of the reality of the markings in question.

The largest of the grey spots was named *Solitudo Hermæ Trismegisti*, or "Wilderness of Mercury the Thrice Greatest"—a fabulous personage, believed by the Greeks and the Egyptians to have invented all sciences, including astronomy. This marking was discovered, among others, by me at Meudon; it had not been seen previously on account of its faintness, and I have shown that medium-sized instruments do not reveal pale half-tones on the planets.[3]

The dark area named *Solitudo Atlantis*, to the right of my map, is certainly much larger now than when it was first drawn 51 years ago. Yet the reality of this apparent change must be considered with the utmost diffidence, as vegetation seems impossible on a world where the temperature rises at least 200° above the zero of the Centigrade scale.

An analysis of past observations has shown me that *all* the most important spots drawn by De Ball, Denning, Schiaparelli, Jarry Desloges, Fournier, and Danjon are confirmed by my own observations; and that the principal markings of my map have been partly confirmed with the 33-inch by Messrs. Ritchey, Lyot, Burson, Baldet, Grenat, Roger, Mlle Roumens, and by M. Swings, of the University of Liège, in Belgium, observing with me Mercury in the large instrument.

[3] *Mars Report for 1909*, in *Memoirs of the British Astronomical Association*, vol. XX, p. 30.

We thus have the converging evidence of many hundreds of mutual, independent, confirmations of the existence of definite spots on Mercury by several well-trained observers, and this *always*, without exception, in the positions necessitated by a period of uniform rotation equal to the period of revolution. Hence the 88^{d} rotation of the planet is now demonstrated established on an immovable basis.

The idea of a rapid rotation, of some 24^{h}, rests merely on analogy with the kindred rotation of Mars and of the Earth; and, apart from the decisive conflicting evidence of observation, it has the further disadvantage of ignoring the important action of the bodily tides. Now, I have shown that Mercury is with reference to the Sun in a position comparable with that of Iapetus with regard to Saturn[4]; and we know, since the days of Cassini, that Iapetus, apart from his librations, presents always the same face to Saturn. The mean distance of Iapetus to his primary is 62 mean radii of Saturn; and the mean distance of Mercury to the Sun is 83 solar radii. But the density of the Sun is double that of Saturn; and, applying the 6th-power law, which governs the frictional force slowing down rotation, we find that Mercury, as above stated, is with the reference to the Sun in a comparable position with that of Iapetus to Saturn. The duration of such tidal actions comes here into play, and somebody may ask if the Sun is as old as Saturn. A cosmogonist, skilled in the arts of grasping the exact manner in which the various globes of the universe were begotten, can alone clear up that mysterious question.

The application of the 6th-power law to the satellites has further enabled me to demonstrate that all those bodies known up to 1893 show, apart from their librations, always the same face to their primaries.[5] The problem had to be set in a very particular way, to which I was led by observation; and that is the reason for which this law governing the rotation of the satellites had eluded the penetration of such profound mathematicians like Henri Poincaré and Sir George Darwin.

The same law will enable us to understand the very reason of

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[4] *Journal of the British Astronomical Association*, vol. 39, 1928, p. 86; letter to Mrs. Maunder.

[5] *Bulletin de la Société Astronomique de France*, vol. 43, 1929, pp. 385-398.

the fundamental difference existing between the rotation of the planets and that of the principal satellites: expressing distances in radii of the primaries, we find that the satellites had their rotation annulled because they were too near their planets; whereas the planets, excepting Mercury, have preserved the independence of their rotation because they were far too distant from the Sun.

Another interesting question is raised by the existence of an atmosphere around Mercury. That gaseous envelope, like the one surrounding Mars, is absolutely invisible; but the frequent presence of cloudy veils over the markings of the superficies constitutes a solid proof of its existence. The clouds of the planet were discovered by the acuteness of Schiaparelli, who found that they often appear as white streaks on the limb, and that they also veil the dark areas, being curiously more frequent on the evening than on the morning phase. The Italian astronomer compared these veils to the clouds of the Earth—a natural, though at present impossible assumption, as will soon be seen. Yet, excepting this comparison, my independent results have entirely confirmed the statements of Schiaparelli on this question of the atmospheric veils of Mercury. The limb of the planet often showed to me temporary, irregular, whitish arcs of cloud, stretching sometimes over 3,000 miles in length. Towards the central regions, these veils tended to become invisible, their presence being indirectly revealed by the temporary pallor, or invisibility, of the subjacent markings of the surface. It was rarely that a spot belonging to the superficies would preserve its intensity unimpaired for many successive days; and the veils in question presented all the degrees of condensation, from the greatest rarefaction up to an opacity which completely obliterated dark areas of the soil measuring more than 2,000 miles across. The changes were sometimes so rapid, that a spot of the length just mentioned, visible with its real intensity through a clear Mercurian air one day, would be utterly invisible 24^h later, and conversely. Very often, the dark areas had their intensity locally diminished for weeks, with an alternate succession of various degrees of pallor, extinction, and final return to their normal appearance. In the course of my enquiry, the hooked dark spot to the right of my chart, named *Solitudo Criophori*, was much more often rendered invisible by local veils than any other marking.

The clouds of Mercury are much more frequent and more obliterating than those of Mars, whose nature is, however, quite a different one.

It is certain that these veils cannot be composed of droplets of water or of particles of ice, like our own clouds. The enormous heat radiated from the Sun renders the existence of water in the liquid state on the sun-lit hemisphere of Mercury impossible, while the deductions of Johnstone Stoney from the kinetic theory of gases make the presence even of aqueous vapour extremely doubtful in the atmosphere of that world. Meantime the low albedo of these clouds, which does not exceed 0.2, is quite different from that of our cumuli at 0.7, so that the only admissible explanation of the atmospheric veils of Mercury is that they are probably due to minute particles of dust, raised by the violence of the winds above the gloom of the dark, scorched, and desolate surface of the planet.

It has been shown by the variation of light with phase that Mercury must have a very rough and uneven soil; and his low albedo seems to indicate the presence, on his superficies, of eruptive rocks, of basalt and dark lava. The varying distance from the Sun must tend slowly to disintegrate the rocks exposed to his heat, and this process of destruction must be particularly active along the borderland of the terminator, where the wilderness is exposed to awful variations of temperature, ranging, indeed, over hundreds of degrees Centigrade.

"Mercury", says Dr. Crommelin, "is probably a parched desert, with nothing to mitigate the intense glare of the Sun on its day side, seven times as fierce as we receive on Earth."[6] Prof. Aitken rightly considers that "the little planet is not fitted to be the abode of life"[7]—a conclusion to which the late lamented E. W. Maunder had independently arrived when he wrote that "the conditions of Mercury are so unfavourable for life that, even if this remarkable relation of rotation period to revolution did not hold good, it would still be impossible to regard it as a world for habitation".[8]

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[6] *The Star World*, pp. 82-83.
[7] *Journal of the Royal Astronomical Society of Canada*, October, 1911.
[8] *Are the Planets inhabited?*, pp. 116-117.

THE CONSTITUTION OF THE STARS

By Henry Norris Russell

(*Concluded from page 391*)

Two principal suggestions deserve consideration. The first, and boldest is that, under certain rare conditions, a pair of the positive and negative charges out of which matter is built—proton and electron—may annihilate one another and disappear, leaving the whole amount of energy represented by their masses to escape, presumably as radiation of very high frequency, which inside a star would soon be absorbed, its energy reappearing as heat in the gas. Could such a thing happen, the annihilation of one per cent. of the sun's mass would keep it going for 150,000 million years. To consume the whole mass, if possible, would take much more than a hundred times as long, for as the mass decreased, the luminosity, and with it the rate of wasting, would diminish rapidly. The second hypothesis derives the energy from the transformation of hydrogen into other elements. The atomic weights of all the heavier elements (that is, of the separate isotopes of the complex ones) are very nearly integral multiples of the unit ordinarily used by chemists; but that of hydrogen is greater by one part in 130. If in any way hydrogen atoms could be broken up and their parts redistributed to form a heavier atom, the protons and some of the electrons condensing into the nucleus, and the remaining electrons forming the rest, there would be a loss of mass which would presumably escape as energy into the surrounding gas. Transformation of the sun's whole mass from hydrogen into other atoms would liberate heat enough to supply its present radiation for 100 billion years (10^{11}). This far more than meets all the demands of geology; but the maximum life, on this hypothesis, for the brightest known stars comes out less than one billion years, which is inconveniently short.

Radioactivity—which is a special case of the transformation of one heavy atom into others—also liberates energy at the expense of loss of mass. The known cases supply heat too slowly to keep the brighter stars going, and in too small a total amount to meet the requirements. Suggestions that heavier and more powerfully

radioactive atoms than any known on earth may exist in the stars are purely speculative.

Very little can yet be said about the possibility of the annihilation of matter inside the stars; but that little indicates that it should not occur except at temperatures of many billions of degrees. More progress has been made in the discussion of the building up of heavier atoms out of hydrogen.

According to Heisenberg's new and very attractive theory, atomic nuclei are built up of protons and the recently discovered neutrons. The incorporation of a proton into a nucleus would in many cases change an atom of a known element into one of the following element (Be^{9} to B^{10}, B^{11} to C^{12}, etc.). The introduction of a neutron would change an atom into an isotope of the same element, but with atomic weight greater by 1. (Li^{6} to Li^{7}, B^{10} to B^{11}). By alternation of these processes the heavy elements might be built up, step by step. When a proton is built in, about 1/130 of its mass disappears and must be represented by heat liberated in the process. Building in a neutron probably liberates heat also.

At distances greater than 1/1,000 of the outer diameter of an atom, protons and nuclei repel one another. A fast-moving proton, rushing directly at a nucleus might, however, get so near it that attraction succeeded repulsion, and thus penetrate the nucleus and become a part of it. Neutrons would not be repelled, and would probably have a better chance of going in. We do not know enough about them yet to estimate the chances; but a tolerable idea of the probability of penetration of a proton can be obtained by means of wave-mechanics. The chance is greatest for the lightest nuclei, which have the smallest charges and repulsive forces. Calculations by Atkinson and Houtermans show that such penetrating collisions would begin to become important when the temperature of the gas rose above a few million degrees. Their predictions have been strikingly confirmed by the recent experiments of Cockcroft and Walton, who found, upon bombarding lithium with protons accelerated by a potential drop of 300,000 volts, that alpha rays—helium nuclei—were given off with a total energy corresponding to 16,000,000 volts. Evidently a proton penetrates a lithium nucleus (charge 3, mass 7) producing an atom of charge 4,

and mass 8 (an isotope of beryllium) which breaks up into two alpha particles, charge 2, mass 4, while the energy represented by the loss of mass sets these in very rapid motion. The number of cases, per million atoms hit, in which this process occurs is of the order of magnitude predicted theoretically a year earlier.

There is then no room for doubt that the synthesis of heavier elements out of lighter ones and hydrogen may actually occur within the star and liberate great quantities of heat.

(7) Promise of Third Success. The Main Sequence

We have already seen that the interior of a star probably contains about 30 per cent. of hydrogen by weight. In the outer parts of the star a large fraction of the remainder are atoms of carbon, nitrogen and oxygen.

If the same is true in the interior (as appears probable), we may apply formulae recently given by Steenholt and calculate how hot the sun's interior should be to provide heat enough, by atom-building, to balance the outward leakage. Assuming that the central "furnace" contains one tenth of the sun's mass, and is 15 times as dense as the mean, we find that the necessary temperature is 15 million degrees if the active atoms are carbon, 21 million for nitrogen, and 28 million for oxygen. An increase of 30 per cent. in these temperatures would increase the rate of heat production a hundredfold; a decrease of 22 per cent. would diminish it in the same ratio.

The theory is still rough; but further refinements are not likely to alter the conclusion that, if the inside of the stars is at all like the outside in composition, a sufficient supply of heat for their needs will be developed if the central temperature is from 20 to 40 million degrees. The latter would suffice even for a very massive and luminous star.

Now we have already seen that the central temperature of the sun is probably 15 or 20 million degrees. We appear to have here, at last, an explanation why it is of its actual size. If it were twice as big it would be about half as hot inside, and far too little heat would be generated to keep it going; if it were half as big, far too much.

The same is true for the whole main sequence. The great white stars at the top radiate far more heat per gram than the red dwarfs at the bottom. They should therefore be hotter inside, especially as their lower mean densities diminish the chance of atomic collisions. Now there are eclipsing binary stars—whose diameters and masses can be found with considerable accuracy—which belong in all parts of the main sequence. If they are built on anything like the same model, the big white stars are actually hotter inside than the little red ones, to fully the extent demanded by theory.

If this theory is even approximately true, no star could reach an internal temperature as high as 100 million degrees, unless either all the hydrogen, or all the other elements from lithium to sodium, had been completely used up. It is noteworthy that there is no known star for which the data compel us to believe in so high a central temperature (as they do compel the belief that the sun's central temperature is several millions of degrees).

Another striking success of the theory of atomic synthesis is Atkinson's explanation of the relative abundance of the lighter elements in the sun. The strength of the spectral lines shows that lithium and beryllium are present in very small proportions in the sun's atmosphere. Boron is more abundant, and carbon, nitrogen and oxygen increasingly so. Now the lightest elements, if synthesis occurs, should be the shortest-lived, and we might expect that lithium and beryllium would be quite gone, having been all built up into heavier atoms. There is still helium there—plenty of it—but there is good theoretical reason to suppose that, though a proton might easily enter a helium nucleus, it would be very unlikely to stick there, so that the building of lithium would be slow. The lithium atoms thus made would not last long before they were in turn changed into beryllium, so the number present at any instant would be relatively small. The "lives" of heavier atoms would be longer, and they would therefore be increasingly abundant.

(8) Unsolved Problems

Notable as the successes of this theory have been, it is still in a provisional stage. It can not yet treat quantitatively of the entrance of a neutron or an electron into a nucleus—though it has

to assume that one process or the other must occur. Nor can it account for the presence in the sun and stars of the heavier metallic atoms, which would not be synthesized in appreciable amounts until after a very long time. Atkinson, who has discussed the matter very thoroughly, believes that some other process, not yet tractable theoretically, must have operated to produce them, and suggests that some of the heavy atoms thus built up may break down with liberation of helium, and thus supply material for further syntheses.

On the astrophysical side, the important sequence of giant stars remains unexplained. They radiate about as much heat, for equal masses, as the white stars of the main sequence; yet their internal temperature and density must both be much lower, unless the central condensation is exceedingly great. They are still a puzzle. It may be, as Atkinson suggests, that they are supplied by the conversion of hydrogen into lithium and other very light elements; or, as Milne believes, that they have small dense cores of high temperatures; or, as the speaker has suggested, that some unknown atomic or sub-atomic process is at work which is actually favoured by low density. It is tempting to imagine that a proton or neutron may enter a nucleus and remain loosely bound there, but be liable to be drawn in deeper, with liberation of energy, after a time. Collision with another atom, during this waiting period, might knock the particle out, and prevent its permanent binding. But this is pure speculation, and need not be taken too seriously.

Despite these difficulties, good progress has certainly been made in interpreting the properties of the stars; and it is remarkable that so much success has been achieved while we are still ignorant of the density-model on which any star, except a few white dwarfs, is built. There is an intimate connection between this problem and the other incompletely solved problem of the source of stellar energy. Given either of them, we could deduce the other, provided that we knew the composition of the material at every point of the interior. "There's the rub"; for the composition involves the specification of the relative proportions of more than two hundred kinds of atoms, including the various isotopes. With regard to the internal temperature and opacity, all elements except hydrogen act very much alike, so that only the percentage of hydrogen is really

important. But, when it comes to the liberation of energy, different elements, and even different isotopes of the same element, probably behave differently, and this would make prediction difficult, even though we knew the laws of atomic synthesis and disintegration exactly. To get anything that we can work with, we must cut the Gordian knot by assuming that the composition of all parts of a star's mass is the same. If this assumption was made solely to facilitate our analysis our position would be embarrassing; but, fortunately, there are good physical reasons to believe that inside a star there will be slow currents, mixing the gas and tending to make its composition uniform.

(9) Model Stars. Vogt's Theorem

Material of exactly specified composition must have perfectly definite physical properties, so that, if the temperature and pressure are given, the density, the opacity, the rate of liberation of atomic energy, and so on, must be calculable by equations, which (whether we know them or not) are exact, and leave no room for ambiguity. If we knew these equations, we could calculate all the properties of stars of the given composition in the following way.

We may assume the star to be rotating so slowly that it is practically spherical. (What happens otherwise is an additional problem, to be solved later, if we can.) The pressure will certainly be greatest at the centre, since the overlying mass is greatest there, and the temperature, too, will be greatest, for otherwise heat would flow from the hotter parts to the centre and could not be accounted for except by the grotesque assumption that the central material consumed heat instead of liberating it.

Start the calculations by guessing at any plausible values of the central pressure and temperature. Then the density, opacity and rate of heat-liberation are determined. Within a small sphere described about the centre these quantities will change very little, so we may calculate the force of gravity at its surface, and the rate of flow of heat outward through it. From these we can find the outward gradients of pressure and temperature at the surface of our sphere, and so estimate their values at the surface of a sphere twice as big—which enables us to extend all our calculations to this second sphere. Proceeding thus, step by step, we may carry

our calculations on as far as we please. This is known as the "method of quadratures." Though very laborious, it is powerful, and will solve a great variety of problems. Proceeding outward in this way, we find the temperature and pressure steadily decreasing—and incidentally calculate the mass inside each successive sphere, and the total outward flow of heat through it.

Finally, the pressure may fall to zero, denoting the outer limit of the mass. Knowing the radius and the heat flow, we can calculate what the surface temperature should be to permit the radiation of this amount into space. The temperature derived from our calculations should be 81 per cent. of this—to make allowance for the fact that the "surface temperature" is an average including hotter layers. This condition will usually not be satisfied—which means that we have made a false start with our guesses at the central temperature and pressure. By changing one of these—say the pressure—and repeating our calculations, we may succeed—usually after a great deal of labour—in getting a satisfactory solution—a model star, made of our given material, for which we know the mass, radius, luminosity, density-model, etc. Then we start with a new central temperature, repeat the whole process and get another model star—and so on.

In this way, by a great but not impossible amount of calculation, we find out exactly what stars of the specified composition would be like.

One thing about them follows at once from the nature of the process of calculation. If we plot any two of their characteristics—say mass and luminosity—in a diagram, all the points representing our solutions will lie on a definite curve—that is, there will be an exact mass-luminosity relation. Similarly, if we plot luminosity against surface temperature, we will get a definite curve. These curves may be of complicated shapes, or even consist of two or more branches; but our points will be on lines, and never be scattered over an area in our diagram. In mathematical language, our model stars form a one-parameter family.

This is Vogt's theorem—the most important general proposition which has yet been established regarding stellar constitution. It has important practical applications. For example, the stars of the main sequence lie so close to one line on the diagram that they

may all be of the same composition. The giants lie close to another line and may be similar in composition *inter se*. Indeed it is possible, though it looks unlikely, that the loci for the giants and main sequence may be two parts of the same curve. But the super-giants are represented by points which are apparently scattered here and there over a wide area in the upper part of the figure. Hence they can not all be of the same composition.

Vogt's theorem would fail for bodies cool enough to permit liquid drops to condense out of the gas—a contingency not to be feared in the stars—and also in the case of a star which derived its heat supply from gravitational contraction—for here the rate of heat production in a given part of the interior depends not merely on the temperature and pressure there, but also on the rate of shrinkage of the star as a whole. But its range of applicability is very wide.

A good many individual models of stars have been computed. In some of these, physically improbable assumptions were made to simplify the mathematical work—for example, that the rate of generation of heat per gram is the same in all parts of a star, though different in different stars. Such models, though of great value in the development of the theory, need not detain us here.

A curious class are the "point-source" models, in which it is assumed that all the heat is generated in one point at the very centre—the rest of the star acting simply as a blanket to keep it from escaping. This is not so crazy as it sounds—it represents the limit of the quite plausible assumption that the heat is generated in a small central region of high temperature.

In some of these solutions, the density diminishes near the centre—the matter being driven away by the enormous radiation pressure. Even with this extreme assumption, the luminosity for a given mass differs by less than one stellar magnitude from that of a model in which the heat-liberation is almost uniform—as Eddington first showed. Biermann, who has calculated several such models, concludes that they may be "finished off" into physically possible stars by replacing the point-source with a small, hot and very dense core—so dense that it is relativistically degenerate. This idea of a dense core was first suggested, long before,

by Jeans, who showed that its existence was probable in stars of large mass.

The first calculations of stellar models with a law of heat-generation derived from theory (atomic synthesis) have recently been published by Steensholt. In the cases so far discussed, the density is less at the centre than half way out to the surface. So much heat is produced in the inner regions, where the temperature is highest, that the point-source model is approached. Some of the theoretical models, therefore, have a partly empty centre, others a very dense centre. A great deal more calculation will be required before the subject is cleared up. The only observational data, on Y Cygni, indicate that in this star the central condensation is high.

(10) Stability

The assumption that a star is in internal equilibrium, which has been the basis of the whole discussion, is justified by the observed constancy of the brightness, spectral peculiarities and other observable characteristics of the great majority of actual stars. But, before any theoretical model can be accepted as satisfactory, we must inquire what would happen to it if its equilibrium should be disturbed.

Possible disturbances may be of two kinds, mechanical, involving changes in the size or shape of the star, and thermal, involving changes in the rate of generation of heat inside, or loss from the surface.

The most important mechanical disturbance is a change in the size of the body. Suppose, for example, that a body, of low enough density to be gaseous throughout, were suddenly reduced to 9/10 of its previous diameter (remaining built on the same internal model). All parts of the mass, being nearer together, attract one another more strongly, and the internal pressure is increased. To maintain equilibrium, the temperature must rise, according to Lane's law, to 10/9 of its previous value in each part of the body—which means that a large amount of energy must be communicated to the gas. During the contraction, however, a great deal of work is done by the gravitational forces, and gravitational potential energy is lost. In the simplest case, when no changes occur in the

atoms of the gas, and no compounds are present, an easy calculation shows that just half the change in gravitational energy would suffice to furnish the necessary heat. Hence the star can not actually contract unless some way is found to get rid of the other half. Radiation from the surface would ultimately bring this about, but the process is very slow. It would take the sun, for example, about 1½ million years to lose enough heat at its present rate to permit it to contract by 10 per cent.

If, by some hypothetical force, such a star should be rapidly compressed to (say) 90 per cent. of its present diameter, the freed gravitational energy would all appear as heat in the interior, the internal pressure would be too great to balance the weight of the overlying layers, and, the moment the constraint was removed, the body would begin to expand. When it reached its original size, all parts of it would be moving outward, and this expansion would overshoot the mark, carrying it to about 10 per cent. larger than normal. The internal temperature and pressure would then be too small, and contraction would ensue, to be followed by another expansion, and so on. The star would therefore show periodic changes in diameter, or pulsations, which would continue for a long time—though, after a great many oscillations, the "leakage" of heat from one part of the star to another might damp them out. The period of pulsation depends mainly on the density of the body. It would be a few hours for the sun, a few days for the yellow giants and many months for the enormous red giant stars.

If, however, the gas of which the star was composed became more heavily ionized at the higher temperature after the compression, part of the surplus energy would be used in bringing this about, and less would be left over to produce the pulsation—which would then be slower for the same density, but the body would still be stable, unless the ionization demanded more energy than the gravitational changes made available. In such a case, the pressure, after contraction, would be inadequate to sustain the load, and the mass would contract further and further, and never return to its original state. In a star made up wholly of one kind of atoms, there might be some chance of this—though not in all parts of the mass at once. But with a mixture such as is actually found in the

stars there is no danger, especially as the abundant hydrogen is completely ionized except in a very thin skin at the surface.

The radiant energy and radiation pressure, by the way, adjust themselves so as to take up just their share of this gravitational energy—leaving the properties of the gas to determine the stability of the body.

A pulsating star should vary periodically in diameter, and also in surface temperature, brightness, colour and spectrum. Now there are hundreds of stars—the Cepheid variables—which change in all these respects, repeating their variations regularly for thousands of periods. The pulsation theory gives a good account of almost all their properties—though it is not yet well understood why the rise in brightness should almost always be more rapid than the fall. They are brightest, and hottest outside, not when they are smallest (and hottest inside), but when they are rapidly expanding, as if the heating effect took time to work out to the surface. They are all super-giant stars, of exceptional luminosity, and their periods, ranging from a few hours to a couple of months, are in good agreement with their probable densities.

Forced changes in the natural spherical shape of a star would also lead to oscillations—of shape, this time, and not of size—but these would involve much smaller changes in internal energy, since some parts of the mass would be hotter while others were cooler, and are much less likely to lead to trouble.

One more type of disturbance must be noted. If a mass of the hot gas deep down should be suddenly raised nearer to the surface, it would expand to the degree permitted by the lowered pressure, and be cooled by a calculable amount. If the temperature gradient in this region is high enough, such a mass might find itself hotter than the surrounding gas, and therefore less dense, so that it would continue to rise of its own accord. In any such region, ascending and descending currents would be set up, and continued until the too-rapid change of temperature had been smoothed out. This effect would operate to change the model on which the star was built, and may cause a good deal of trouble to the theoretical calculator, but it is not likely to upset the stability of a star—though, if the convection currents are irregular, it might cause small irregular variability in brightness, as Rosseland suggests.

Thermal disturbances within a star have to do with the balance between the production of heat within it and the loss by radiation. They act slowly, because the store of heat already inside a star is so great. For example, the sun's interior contains, in the form of actual heat (disregarding potential energy of all kinds), enough to supply the present rate of radiation for some ten million years. If the supply of heat from subatomic sources were completely cut off, a slow contraction would ensue; if it were doubled, the excess would be consumed in forcing an expansion against gravity at the same rate. Even if 100,000 years' heat supply should be suddenly liberated (not at one point, of course, nor too near the surface), the effect would only be to increase the radius by about one per cent.—accompanied by pulsations about the new value. This expansion, by Lane's law, would lower the internal temperature. We have here an apparent paradox. A gaseous star, considered as a whole, has a negative specific heat; liberation of heat inside it cools it. The explanation is that the addition of this heat energy forces a much larger transfer of heat into gravitational potential energy—reminding one of the effect of a resisting medium in increasing the orbital velocity of a comet.

Suppose now that we have a star in radiative equilibrium—and that the hypothetical disturbing agency not only diminishes its diameter, but at the same time abstracts from it the excess heat freed by the contraction—so that there is no longer any tendency to pulsate about the new radius. Under the changed conditions both the income of heat from internal sources and the expenditure at the surface will be altered. If the two still balance, the new configuration will persist unchanged. If the income exceeds the outgo, the star will slowly expand, and return toward its initial state; it is secularly stable. In the opposite case, it is unstable, and will depart further and further from its original state. The condition for stability is therefore that the rate of heat production shall increase more rapidly, with increasing temperature and density, than the rate of outflow. It is easily verified that this also secures stability in event of a forced expansion.

These changes are unlike the mechanical pulsations in two respects. First, they are vastly slower, with a time-scale of millions of years (tens of thousands for the brightest giants), instead of days

or months. Second, the return to "normalcy" is steady, without oscillations.

Heat-liberation by atomic synthesis increases very rapidly with the temperature, and satisfies the condition for stability; but heat production at a rate independent of pressure and density (such as arises from radioactivity) does not.

There is, however, another more subtle danger to which our star is exposed. Any disturbance is likely to set it pulsating. When smallest, it will be hottest inside, and the rate of heat production will be greater than the average. This tends to make the rebound a little greater than the contraction which preceded it, and so to build up the pulsation with steadily increasing amplitude. This effect has a long time-scale, like the last—as Jeans has shown—but it is ultimately serious. Eddington, who first pointed it out, suggests that it may be avoided by assuming that the heat-liberating process does not act instantly, but with a time-lag greater than the period of pulsation. This would "iron out" the irregularities and prevent trouble. Such a lag may easily occur in processes of atomic synthesis, provided that, as Atkinson suggests, the main liberation of heat occurs when the products at first synthesized break down.

An increasing pulsation need not necessarily grow till it breaks up the star altogether—it is entirely possible that, when the amplitude becomes considerable, secondary effects may slow up, and finally prevent, further increase of range. Stars for which the stability condition was not satisfied might then be started pulsating by the least disturbance, but the pulsation would increase only to a certain limit. The Cepheid variables behave in very much this way; they are never more than three or four times brighter at maximum than at minimum, and the change in diameter (derived from the observed radial velocities of the expanding or contracting surface) does not exceed 20 per cent. on each side of the mean. It is probable, though not proven, that these stars are actually unstable, in the sense here discussed, but that their pulsations are self-limited.

Jeans has shown that the tendency to pulsatory instability increases with the mass of a star. The Cepheids are among the most luminous, and hence presumably the most massive, of all stars.

The period-luminosity relation among them—which has been so important in determining the distances of remote star-clusters and nebulae, may well represent the relation between the mass of a star and the density at which this instability begins to appear. A really satisfactory theory of the energy-supply of giant stars should explain this relation as a by-product.

(11) History of a Star

The probable life-history of a star presents the most difficult problem of all. It is natural that the path of advancing knowledge regarding the physical constitution of the stars is strewn with the corpses of dead theories of their evolution. We are not far enough along yet to possess the basis for really constructive work on the subject.

The conclusions which can be drawn from our present limited knowledge depend greatly upon our assumption regarding the source of stellar energy. If the greatest available supply is the synthesis of other elements from hydrogen, a star's mass will change very little during its whole life. Beginning, we may imagine, with large radius and low density, it will at first have to draw on its gravitational energy and contract after the manner discussed by Kelvin, until it gets hot enough inside to start the process of synthesis. It will then approach a steady state, in which it will remain, with little change in size or other observable properties, until the active material—whatever it may be—is nearly exhausted. Then it will again begin to contract, and grow hotter inside, pausing again, perhaps, if some new energy-liberating process is "turned on" at a higher temperature. Finally, after all the available sources are exhausted, it will contract until degeneracy sets in at the centre, and then pass through intermediate stages of the type discussed by Milne, into a state of great density. If its mass is small, it will be successively a white dwarf, a yellow dwarf and a black dwarf, finally extinguished. If its mass is large, it may contract to exceedingly small dimensions and be lost to all observation.

During this process its luminosity will increase slowly, till degeneracy sets in, and will fall rapidly as it becomes advanced. The maximum length of a star's life as a luminary—between the times when it gets hot enough on the surface to be visible, and

when it reaches the degenerate stage—may be estimated by assuming that it was composed of almost pure hydrogen at the start, all of which becomes transformed. The result varies greatly with the star's mass, being 10^{11} years for the sun, and not more than 500 million for a super-giant of mass 50 times and light 10,000 times the sun's. This last figure is uncomfortably small; it makes the star's life shorter than geological time, and only four or five times longer than the interval during which light from the more distant nebulae has actually been on the way to our spectroscopes.

The relative lengths of time which a star will spend in different stages will depend upon the amount of transformable matter available to keep it going in each, and this, again, may depend on the breakdown of atoms formed in earlier stages or earlier in the existing stage (as Atkinson suggests). Knowledge of these is essential to any detailed prediction of the stages in which the stars will linger long, and in which therefore the majority of them will be found. Till this becomes available, we may well hesitate before pronouncing one star to be older or younger, in years, than another.

Suppose, for example, that there were many stars, of different masses, all composed of hydrogen and oxygen, or hydrogen and nitrogen, and all initially of very low density, and that the only process of atomic synthesis is that discussed above. They would perform "Kelvin contractions" till their central regions reached, approximately, the temperatures possessed by the various stars of the main sequence, and then would settle down with the corresponding radii, densities and surface temperatures. A massive star might become stabilized, with spectrum of class B, in a few hundred thousand years. A star of small mass might take scores of millions to reach a spectrum of type K or M; but, after they had done so, both would remain substantially unaltered for a long interval.

The white dwarfs show apparently definite signs of senility; but even here we must be on our guard against dogmatism in attributing this to greater age, for we do not know whether they started with the same composition as the others, or what has happened to them in the meantime. The fact that many of the known white dwarfs are components of binary systems, whose other members belong to the main sequence, suggests that, after all, they may not be much older than other stars—only more

decrepit. If they have passed through such intermediate stages of contraction with very hot centres as have previously been described, it is hard to see how any hydrogen can be left inside them—though their atmospheres might still contain it, as their spectra indicate. But it is well to be cautious.

If annihilation of matter takes place within the stars on a large scale, their lives may be hundreds of times longer, and a star, during its history, may diminish greatly in mass and in luminosity. The possible life-histories may be much more complicated, depending on how much mass is lost by the consumption of various kinds of expendable material in different stages. The early stages of large mass and great luminosity will be relatively short, and the final faint stages of very long duration. Provided that any indestructible atoms remain, the final state is a black dwarf, as before.

The great problem of the longer or shorter time-scale may find its solution in another way. The theory of the expanding universe indicates that at a relatively recent time—something like 10^{10} years ago—the universe was probably either just beginning to expand perceptibly after a previous eternity of sluggishness, or very much smaller than at present, and expanding rapidly. The latter type of theory—adopted in different form by Lemaitre, Tolman and de Sitter—leaves hardly time enough for much change even in a massive star, and certainly none for a star of smaller mass. If such an epoch of intense cosmic activity occurred in the relatively near past, the stars may be indeed all of the same actual age, and may, with few exceptions, still be almost fresh from the mint—"in their first innings" as Eddington puts it. On Tolman's hypothesis, the universe previously to this "age of confusion" was contracting after a long history. It is perhaps permissible, and certainly attractive, to suggest that dense bodies like the white dwarfs may be survivors of this earlier world, which have come unscathed through the cataclysm.

Once again, we lack many data necessary for a definite solution. We do not know whence the stars arose, nor what their histories have been. But so much of the nature of the greatest material objects in nature has already been revealed from the study of the minutest that there is better reason than ever to hope, with Eddington, "that in a not too distant future we shall be competent to understand so simple a thing as a star."

THE LEONIDS IN 1933

THE appearance of the Leonids this year was rather disappointing in view of the numbers seen during the past two years. Fewer Leonids were observed in 1933 than in 1932, this in spite of the fact that there was a nearly full moon on the latter date which cut out all the faint meteors, while this year the maximum night came at the time of new moon.

Stations for the visual and photographic observation of the Leonids were organized at the new David Dunlap Observatory near Toronto and at Brampton, Ont. These were supplemented by smaller groups which observed at various points in and near Toronto. Reticles were used at the David Dunlap Observatory and at Brampton.

A special effort was made to secure more Leonid spectra. Stations co-operating in the spectrophotography of meteors included the David Dunlap Observatory, Richmond Hill, Ont.; Saskatoon, Sask.; Oak Ridge Station of the Harvard Observatory, Harvard, Mass.; Blue Hill Observatory, Blue Hill, Mass.; Hopkinton, Mass.; Ensley, Ala.; and Ft. Worth, Texas. At several stations Eastman IC Special red sensitive plates were used in the hopes of photographing a meteor spectrum in the red. The weather was clear at the majority of the above stations but it is yet too early to give a complete report on the results of the photographic programme.

The visual observations have not yet been reduced but it was a noticeable fact that both in Massachusetts and Ontario more and brighter Leonids appeared on the night of November 16-17 than on the previous night. November 17-18 was cloudy at both localities. The small numbers of Leonids observed this year should not discourage further Leonid observations as it must be remembered that the greatest numbers of meteors at the last Leonid return were seen in 1901 and it is quite possible that the Leonids may appear definitely more numerous sometime during the next three years.

P. M. M.

REVIEW OF PUBLICATIONS

A Star Atlas and Reference Handbook by Arthur P. Norton, the maps being completely revised with new I.A.U. boundaries. 100 pages, 8½ x 11 in. London: Gall and Inglis; also supplied by Eastern Science Supply Co., Boston. English price 12*s.* 6*d.* 1933.

The first edition of this work appeared in 1910 and it is gratifying to see a fifth edition called for. There are 18 excellent maps, which have lists of objects printed on the back of them in a convenient place for reference. In addition, there are two key maps. Besides, there are some sixty pages of condensed information. This includes astronomical tables required by every amateur; notes on astronomical terms, stars, nebulae, the sun, the moon, the planets, the galaxy; hints on observing and the use of the telescope; remarks on spectroscopy and the atom; pronunciation of constellation names and the approved abbreviations for them. There is a surprising amount of information on each of the large pages. It is brought up to date, and includes references to the Delporte and Reinmuth minor planets of 1932.

The atlas is primarily designed for amateur telescopists possessing instruments without graduated circles. It is a suitable companion to Webb's "Celestial Objects for Common Telescopes" and Smyth's "Cycle of Celestial Objects", and is a very useful work to have around any observatory. The maps contain 8,000 stars, which include the seventh magnitude, and 600 nebulae.

C. A. C.

Précis d'Astronomie by Paul Stroobant, director of the Royal Observatory of Belgium. 189 pages, 6¼ x 8¼ in., 49 figs. and a map of the stars from the north celestial pole to declination −15°. Paris: Gauthier-Villars. Price 30 fr. 1933.

This is a new and enlarged edition of a work published under the title *Précis d'Astronomie pratique*. It contains an excellent summary of the main principles and results of astronomy, generally

without proofs. There are ten chapters: (1) Fundamental notions. (2) General considerations of the earth. (3) Methods of observation. (4) The sun. (5) The motion of the earth. (6) Measurement of time by the sun. (7) The moon. (8) Planets and comets. (9) The sidereal universe. (10) Universal gravitation.

There are few astronomical terms which are not defined and clearly explained. Indeed the work is a valuable handbook to have beside one, but it would be improved if an index were added. As usual with this publisher's books, the typography is superior.

C. A. C.

NEWS AND COMMENTS

Notes from the Dominion Astrophysical Observatory, Victoria, B.C.

In continuation of the observing statistics from the May-June issue of this Journal, we have the following from the records of the observatory:

Month	1933		14-year average	
	Nights	Hours	Nights	Hours
May	15	67	21	108
June	17	73	19	89
July	23	115	25	131
August	22	146	24	147
September	13	83	20	150
October	16	140	16	124

The number of visitors while much below those of a few years ago continues to show an increase this year over last year. For the six months listed above the total was 15,403 as compared with 12,054 for the corresponding six months of last year. Is such increase an index of returning prosperity? Let's hope so!

Your scribe cannot record any outstanding astronomers who have visited us since May, when we had a great number for the Pacific Science Congress. This event was somewhat fully written up in a previous issue.

The Director, Dr. J. S. Plaskett, spoke on a recent Sunday evening from the pulpit of Christ Church Cathedral of this city on the theme "Science and Religion."

The Assistant Director, your scribe, spent a couple of days the past month in Vancouver speaking to the Astronomical Society on "The Dominion Astrophysical Observatory and Its Work" and to the science students of the University on "Shadows."

W. E. H.

NOTES AND QUERIES

Communications are invited, especially from amateurs. The Editor will try to secure answers to queries.

Death of Lady Parsons

Lady Parsons died on October 16, aged 74 years, at her beautiful country home at Ray, about twenty miles from Newcastle-on-Tyne. She was the widow of Sir Charles Parsons, the inventor of the steam turbine, and known to astronomers as a son of the Earl of Rosse, who completed a 6-foot reflecting telescope in 1845, and also as the real head of the firm of Sir Howard Grubb, Parsons and Co., which has in recent years constructed a number of large telescopes, including the 74-inch reflector for the David Dunlap Observatory of the University of Toronto. Sir Charles died in February, 1931, and a sketch of his life appeared in this JOURNAL, volume 25, p. 185 (1931).

Lady Parsons' maiden name was Katharine Bethell, of Rose Park, Yorkshire, and she married Charles Algernon Parsons in 1883. Her intellectual ability and mechanical taste allowed her to appreciate her husband's great achievements. A son, Major A. G. Parsons, was killed in action in 1917 while serving with the Royal Artillery in France. A daughter, Miss Rachael Parsons, survives. She has the distinction of being one of the three women members of the Institute of Naval Architects.

Lady Parsons was buried beside her husband in the little village churchyard at Kirkwhelpington. The account of Sir Charles' life referred to above contained two plates, one being a photograph of Sir Charles and Lady Parsons taken at Ray by the present writer. A copy of the sketch was sent to Lady Parsons and I take the liberty of printing her reply below.

Ray Demesne
Kirkwhelpington, Northumberland
July 4th, 1931

Dear Mr. Chant,

I received your letter of June 1st, and thank you so much for sending me a copy of the Obituary you wrote on Sir Charles. I think it is an excellent account of the main features of his life and work, and you have dealt with it all in a very appreciative and sympathetic manner. I am very pleased indeed to have it.

I had forgotten the photograph. It is very good in spite of the misty weather.

I hope very much that I shall meet you all again some day.

With many thanks.

Sincerely yours,

KATHARINE PARSONS.

THE LATE H. E. S. ASBURY

Many friends of the late Mr. H. E. S. Asbury will regret to hear of his death on October 23, 1933, in Montreal after two years of ill health, for Mr. Asbury had taken an interest in the furtherance of astronomical knowledge for the greater part of his life and particularly during the past twenty years as an active member of the Royal Astronomical Society of Canada.

In 1910 Mr. Asbury and Mr. Westoby founded a Centre of the R.A.S.C. in Guelph, and subsequently on his coming to reside in Montreal, Mr. Asbury was one of those principally responsible for the founding of the Montreal Centre, of which he served as Secretary and later as President for some time. He purchased a good 6-inch telescope and gave generously of his time and energy spreading interest in astronomy. He has been a member of the Council of the Montreal Centre for many years.

His friends in astronomical circles in Montreal are glad to have this opportunity of paying a tribute to his memory.

A. VIBERT DOUGLAS.

A NEW SUN SPOT CYCLE

It has been found that about sixty per cent. of the spots on the sun come in pairs, with the line joining them approximately parallel to the sun's equator. One spot shows the characteristics of a north magnetic pole; the other, those of a south magnetic pole. Also, if the preceding spots of one cycle in the northern hemisphere show north polarity those in the southern hemisphere show south polarity. In the next cycle the polarity of the spots in the two hemispheres is reversed.

This reversal of polarity has just been observed at the Mount Wilson Observatory and the spots are appearing in high latitudes. Hence it can be said with certainty that a new cycle has begun.

During July and August there was practically no activity on the sun's surface; it was slightly active in September and nearly inactive in October.

THE LONG TELESCOPES MADE BY HUYGENS

All who have studied the history of the telescope will remember the instruments made shortly after 1650 by Christian Huygens and his brother Constantine. In order to overcome aberration the focal length of the lens was made very great—one being 210 feet. A lens of 6 inches aperture and 123 feet focal length was presented to the Royal Society and is still in its possession. In a telescope using one of these lenses the objective was at one end of a spar or girder and the eyepiece at the other, and the whole was supported on a high mast. One is surprised at the results obtained by the skilful handling of these instruments.

The present writer's attention was recalled to these famous old telescopes by a paragraph in "Astro-Theology" by W. Derham, an astronomer of repute in his day. (10th edition, 1767). The last paragraph of his preface reads as follows:

> And now for a close, I shall take this opportunity of publicly owning, with all honour and thankfulness, the generous offer made me by some of my friends, eminent in their stations, as well as skill and abilities in the laws, who would have made me a present of the May-pole in the Strand (which was to be taken down) or any other pole I thought convenient for the management of Mr. Huygens's glass. But as my incapacity of accepting the favour of those noble Mecœnates, hath been the occasion of that excellent glass being put into better hands; so, I assure myself, their expectations are abundantly answered, by the number and goodness of the observations that have been, and will be made therewith.

C.A.C.

MEETINGS OF THE SOCIETY

AT VANCOUVER

October 10, 1933.—The eighteenth regular meeting of the Vancouver Centre was held at the University of British Columbia. The president, Mr. Teasdale, was in the chair.

The speaker of the evening was Mr. W. E. Harper, M.A., Assistant Director of the Dominion Astrophysical Observatory at Victoria, who was introduced by Mr. Teasdale.

Dealing with the subject "The Dominion Astrophysical Observatory and its Work", Mr. Harper pointed out that the observatory at Victoria is an offshoot of the Ottawa observatory which was established about the time the C.P.R. completed its transcontinental line. After the survey work was carried out by the national observatory under the direction of Dr. King, a demand arose for further expansion and in 1905 the Ottawa observatory was established. The survey work was continued, and the provision of a 15-inch telescope and other equipment made it possible to carry on a study of solar rotation, as well as the motion of stars in the line of sight.

By 1910 all the brighter stars had been investigated, and in that year the 60-inch reflecting telescope at Mt. Wilson was completed. Estimates were obtained in 1913 by the Dominion Government for a 72-inch telescope, which was to be a reflector, in view of the many advantages of reflecting telescopes over refractors for instruments of such large size.

At that time Mr. Harper was commissioned to make tests of conditions across Canada, with a view to establishing the best location for the new telescope, and the result was the choice of Victoria on the grounds of steadiness of image and low annual temperature range.

The big mirror was cast in Belgium and was shipped from Antwerp one week before war was declared. The grinding was carried out by the Brashear Company and was accurate to one four hundred-thousandth of an inch. In the spring of 1918 the completed mirror was shipped to Victoria.

Mr. Harper then showed a number of very interesting slides of the observatory in course of construction. A new feature in the mounting of the telescope on ball-bearings was introduced by Dr. Plaskett and has proved entirely satisfactory.

Since the establishment of the observatory at Victoria the staff of eight has carried on an extensive programme of work on such subjects as radial velocities of stars, and orbits of spectroscopic and eclipsing binaries. The radial velocities of 2900 out of a total of 7700 stars for which these values have been obtained is no mean record for one observatory, and of the orbits of spectroscopic binaries one-third have been determined at Victoria.

In conclusion Mr. Harper pointed out that time did not permit him to

mention much of the work which has been accomplished at the observatory, and emphasized the fact that the object of these researches was not towards a practical end, but purely for the advancement of scientific knowledge.

WILLIAM URE, *Recorder*.

AT OTTAWA

February 17, 1933.—The Ottawa Centre held their second public lecture of the season at the Victoria Memorial Museum. The president, Mr. R. Glenn Madill, was in the chair.

The speaker of the evening was Mr. J. U. Beauchemin, C.E., of the Canadian Hydrographic Service, at Ottawa. His topic was "The Gyro-Compass and Echo Sounder"—two instruments which have lately been developed to make the sea a safer place for navigation, and which have been adopted for the past three years by the Canadian Hydrographic Service for charting and oceanographical purposes. The following is the text of the lecture:

The vital importance of an efficient compass and sounding apparatus and the necessity for their use cannot be exaggerated. There are many times when the safety of the vessels and the lives on board would depend to a great extent on the accurate and rapid determination of a course and the depth of water underneath the ship. To substantiate this statement, reference need only be made to the existing facts in many cases of stranding. There is no doubt in my mind that anyone who will review the records of marine disasters for the past five years will readily admit that there is need for an improvement in the present methods of safeguarding navigation to prevent such occurrences.

During the year 1932 an aggregate of 440 ships of 950,000 gross tons, were total losses due to stranding or striking rocks, according to "Lloyd's Register of Shipping". A conservative estimate of the value of these ships is $7,500,000, not including the cargo. The majority of these strandings and groundings, I believe, are from lack of knowledge of exact position due to an unreliable compass and unreliable sounding device. Therefore, I feel you will be interested in hearing something of two instruments, designed to safeguard navigation; namely, the reliable Gyro Compass and the Echo Depth Finding instrument, the latter infinitely more effective than the time honoured lead and line.

Some fifty years ago when the Canadian Hydrographic Service was being launched on its mission of public service, surveying in this country was a crude art. Our great national evolution has produced radical changes in the character and extent of this service to the public. The mission of the Hydrographic Service is to furnish certain data and products indispensable to the orderly and economical existence of activities vital to national well-being. Without our nautical charts, freight and passenger traffic throughout our inland and tidal waters, will cease to move. The Service's contribution to science have been mostly incidental.

There seems to be an unwritten law to the effect that the Federal Government shall not engage broadly and avowedly in scientific research, but this cannot be

applied to the Hydrographic Survey. Such research is undertaken from time to time, but it has, always, as its objective some definite limited purpose.

The service penetration into scientific fields has been of this character, and the resulting benefit to science has been twofold: (*a*) Accumulation of data made available to scientists outside the Federal service, as, for instance, the determination of the densities and salinitica of sea water at different depths; (*b*) The study of such data by the engineering personnel, as, for example, the systematic observation of the rise and fall of the tides at hundreds of points along our coast, in order that the mariner may make practical use of the data thus obtained. The bureau has studied terrestrial magnetism, both on sea and land, especially the former, in order that the mariner may have knowledge of this important factor in navigation, and this year the Service is entering its 35th consecutive year of a systematic charting the depths of the coastal waters and studying their circulation. By reason of the resulting close contact with scientific progress, the Service through the latter years had adopted for its own purposes the results of a long series of scientific achievements, which enabled it to do more and better work at steadily decreasing unit cost.

The important fact is that without this mutual beneficial relationship, the survey could not have attained the position of useful service which it now occupies and the country, not the surveyor or science, would have been the principal loser.

Since the war our nation has been more ship-minded and more thought has been given to hydrography and its methods than ever before. New ideas and inventions have made some drastic changes in the work. Our bureau has endeavoured to keep pace with the changes and is pleased to feel that it has made worth-while contributions to navigation, mainly, in being the pioneer in the use of the gyro compass and echo recording sounding device, for the accurate prosecution of the work in charting our coasts.

The Gyro Compass.—What are the advantages of the gyro compass over the old magnetic compass, this mainstay of navigation for centuries? The drastic change from wooden ships to iron and steel vessels developed difficulties in the use of the magnetic compass, as this type of vessel interferes, to a greater or lesser extent, with the magnetic field of the earth acting upon the compass. Magnetic surveys have been extended over the major parts of the frequented waters and on the adjacent land by the Hydrographic Service and the different branches of the Department of the Interior, so that at the present time correct magnetic information appears on all the mariner's charts, and through the constant and loyal co-operation between our survey and the Department of the Interior, the variation is fairly well established, together with the different disturbed magnetic areas. But the ship's magnetic compass is also subject to very important disturbances called "deviation". For years magnetic compass designers spent their efforts to produce compensating devices that would annul the effects of all the external influences, so that the magnetic compass would be free to indicate only the direction of the earth's magnetic lines as shown on the charts, but these compensating devices have the effect of weakening the direction forces of the mariner's compass, especially in northern latitude.

But the navigator has also to keep in mind that there are several accidental sources of unusual deviation, such as the nature of the cargo, an improper insulation of radio circuits, lightning, running with forced draft causing the overheating of the stacks, rolling, pitching, uneven keel, and many shipwrecks have been traced to some unexpected change in compass deviation, due to those factors.

Now that ships cost millions of dollars to build and thousands of dollars, per day, to operate, time has become the most essential element in navigation, which really means, that the ship has to be navigated from one point to another by the shortest possible course in the quickest possible time.

The gyro compass is universally acknowledged now as one of the most valuable navigational instruments yet devised, for it has wiped out all the complications that exist in the old magnetic compass. The gyro compass on a ship always points towards the true geographical north, and gets its direction force from the earth's rotation and the force of gravity.

How the earth's rotation is utilized.—Any wheel mounted so that its axis can turn freely to any direction is called a "gyroscope". Suppose we were to place such a small revolving wheel supported by its own axis upon a larger wheel, which also is revolving, the rotation of the larger wheel would so influence the smaller wheel that its axis would point in the same direction as the axis of the larger wheel. This is in accordance with the natural law which operates as unfailingly as the law which causes an unsupported body to fall to the ground. Suppose the larger wheel happens to be the earth, which in reality is a revolving wheel, and the smaller wheel to be the spinning wheel of a gyro compass, in accordance with the natural law just mentioned, the smaller wheel of the gyro compass will point its axis in the same direction as the axis of the earth; in other words to the true geographical north.

This explanation of the principle of gyroscopic motion is certainly crude; it can be proved by mathematics to the satisfaction of the most exacting scientist. You would hardly expect, however, that so great a scientific man as the late Professor Rankin, when he was seized with the poetic fervour, would err even more than an ordinary lecturer in making his accuracy of statement subservient to the exigencies of the rhyme, as well as the necessity for simplicity. In his poem, "The Mathematician in Love", he has the following lines:—

> The Lady loved dancing; he therefore applied
> To the polka and waltz an equation;
> But when to rotate on his axis he tried,
> His centre of gravity swayed to one side
> And he fell by the earth's gravitation.

So, without going into an elaborate discussion of the principles and theories of this device, let us admit for now that in the gyro compass we have an instrument which depends, for its direction force to point true north, on two constant and reliable phenomena: the rotation of the earth and the force of gravity.

The gyro compass is more expensive than its predecessor the old magnetic compass. Its existence is, therefore, based on the deficiencies of that compass. The reasons for the widespread adoption of the gyro compass are numerous,

but can for the most part be reduced to the statement that it improves the ship's safety and the operating efficiency, *i.e.*, the ratio between the energy expended and the effect produced.

The Echo Recorder Sounding Device.—In hydrographic surveys the two principal considerations are the taking of soundings, or the measuring of ocean depths, and locating the positions of these soundings. Even with the aid of every possible mechanical appliance the taking of soundings has always been a slow laborious process. Through the co-operation of the British Admiralty and the Canadian Hydrographic Service, a private British corporation has been assisted in developing an apparatus for measuring ocean depths by means of echo sounding.

Echo sounding depends upon the fact that if a sound is produced under water, an echo will return from the bottom. By measuring the time interval required for sound to travel from the hull of a ship to the ocean floor and return to the ship, and multiplying by one-half the velocity of sound in water, the depth of water is determined. Sound travels much faster and easier in water than in air, the velocity being about 4,850 feet per second.

There are three principal units in the echo sounding device of the *Sonic Type*: the transmitter which produces the sound; the hydrophone which picks up the echo; and the receiver which contains the time-measuring device for reading the depth of the water. The sound impulse in the sonic system is produced by a blow from a spring-driven electro-hammer or a pneumatic hammer on a steel diaphragm which is in contact with the water in a tank secured on the ship's hull; the sound impulse is transmitted through the water to the hull of the ship which acts as a diaphragm and re-transmits the impulse to the sea outside the hull. The echo from the bottom is received in a hydrophone which is secured in a tank in the same manner as the transmitter. The hydrophone consists of the microphone and diaphragm which are set into vibrations by the echo. The transmission is controlled by an automatic drum switch revolved by a motor with a governor to keep the speed constant, and a reduction gear which is varied according to the maximum depth and the scale required.

In the latest form of echo recording device, returning echoes are impressed electrically upon the grid, or controlling electrode of a thermionic valve to permanently mark a continuously slow moving paper. Inserted in the anode circuit of the valve are two electrodes—one being the recorder pen and the other carrying the sensitized paper. The paper on which the pen is travelling is treated with a starch iodine solution automatically moistened, rendering it very sensitive to minute changes in current density. The effect of the current passing through the paper is to decompose the electrolyte, allowing the free iodine to combine with the starch, producing a strong purple colouration which changes to brown when the paper is dry. The recording pen is carried across the paper, which is 6″ wide, in two thirds of a second, corresponding to a depth of 250 fathoms on the scale.

During the past three years the apparatus successfully passed all tests and was accepted for use in hydrographic surveys, and steps are being taken to procure additional echo sounding machines and install them on all our survey ships.

By means of the echo recording device of the "Acadia" type, named after the first hydrographic vessel to use the echo in Canadian waters, it is possible without stopping the ship to register on a graph, in any depth from a few fathoms under the keel to at least 1800 fathoms or 10,800 feet. The advantage of the apparatus for survey work is that, soundings can be taken at the rate of 24 per minute, or a sounding every 40 feet, steaming at 10 knots. It is therefore possible to survey a much greater area per day than would be possible by any other means. This apparatus, however, is not confined to the use of the hydrographer, in fact it is of even more value to the navigator since the master of a vessel equipped with an echo sounder can feel his way at night or stormy weather, without stopping the ship. He can also find his position at sea by comparing a series of soundings with the depth shown on a reliable chart, and with this information lay out a safe course to his port of destination.

While the primary purpose of our office in going through these trials and co-operating with the British Admiralty in the development of the echo sounder was to secure an apparatus that would enable the bureau to speed up its hydrographic surveys, it was nevertheless influenced by the belief that the perfection of this instrument would be of great benefit to mariners and would contribute towards greater safety at sea.

The Chief Hydrographer's estimate of the echo recording device has been fully justified and his co-operation has been of material assistance in bringing to near perfection a very important contribution to navigation.

Naturally the efficiency and accuracy of this sounding apparatus attracted the attention of owners of passenger and cargo vessels, for a sounding device that could prove reliable in such exacting services most certainly held advantage for commercial navigation. The last few decades have witnessed many startling applications of science to industry, and those inventions have nowhere shown themselves more fruitful than in increasing speed and safety. The rapid progress of recent years in the echo sounding machine is all the more noteworthy when compared with the centuries that the lead and line remained unchallenged means of ocean depth finding.

The echo method which requires no mechanical connection with the bottom, represents a radical and brilliant step in man's mastery of the sea.

The natural foundation for a ship is sea water. Any well found ship-shape, modern seagoing steamer, sailing vessel or motor ship, is safe so long as she has plenty of water under her keel, plenty of fuel in her bunker, and a competent navigator on her bridge. Naval architects have provided a safe commercial seagoing hull and every branch of engineering and science has contributed to that composite marvel, the modern passenger and cargo vessel, with the net result that today sea transport is the safest and most economical method known to man. In fact, the only real danger to a modern vessel at sea is that uncertain quantity, the personal element. Let a vessel be supplied with every effective equipment for safeguarding, for maintaining the economy of her propulsion plant and for aiding the comfort and peace of mind of her passengers, and yet she will surely go ashore, or be a hog for fuel, unless her navigating officers and engineers

are constantly on the alert to use intelligently the equipment with which she is provided.

One of the worst features of the personal element is the almost universal tendency in the human mind to get careless in the matter of simple routine. This is particularly true of navigation equipment.

It seems that the hydrographic services having provided the modern charts, and science the safe navigation devices, the gyro compass and the echo recording device, the shipping interests should formulate some plan for their constant use, especially in northern waters. At sea as everywhere else, we are continually reminded of the truth of the old adage,—"Eternal vigilance is the price of success and safety".

Two thousand years ago the great poet Homer predicted that the use of a modern hydrographic chart, gyro compass with its automatic gyro pilot and the echo recording device for bringing a ship safely to port, in the following lines:—

> Say from what city, from what regions tossed,
> And what inhabitants those regions boast?
> So shalt thou quickly reach the realm assigned,
> In wondrous ships, self-moved, instinct with mind;
> No helm secures their course, no pilot guides;
> Like man intelligent they plow the tides,
> Conscious of every course and every bay
> That lies beneath the sun's all-seeing ray.

Throughout the lecture Mr. Beauchemin illustrated various points by means of lantern slides.

MIRIAM S. BURLAND, *Secretary, Ottawa Centre.*

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